DE LA RECHERCHE À L'INDUSTRIE

THE FRENCH NUCLEAR FUEL CYCLE:

CURRENT STATUS AND POSSIBLE FUTURE OPTIONS

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CEA, Nuclear Energy Division

1 – The current french nuclear fuel cycle

2 - Trends and options for the future

3 – Challenges for R&D

International Conference on the management of spent fuels from nuclear power reactors: an integrated approach to the back-end of the nuclear fuel cycle

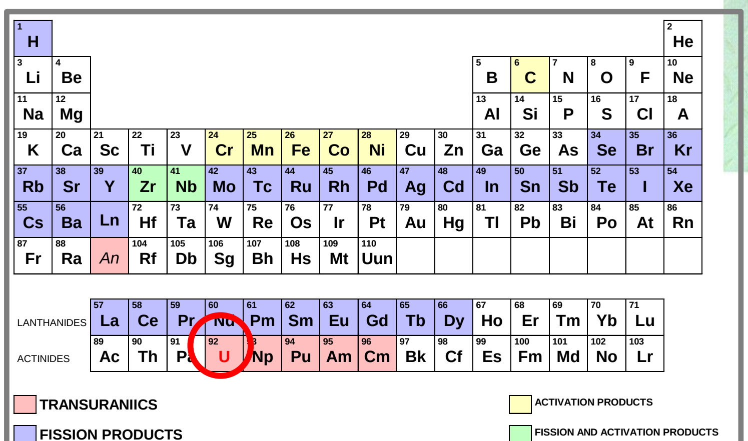
Vienna, June 2015

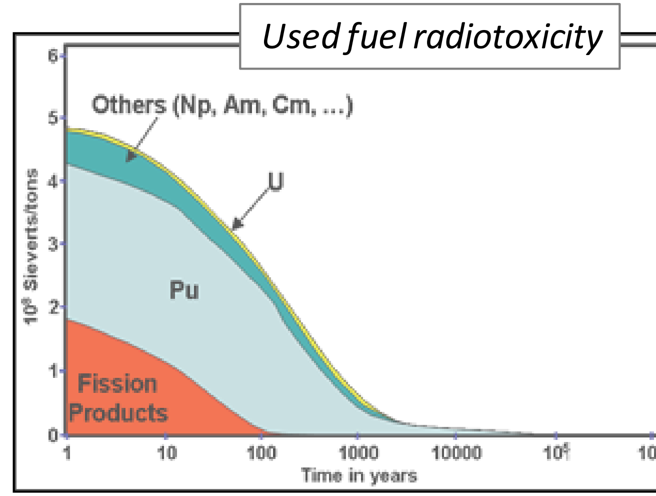
www.cea.fr

USED NUCLEAR FUELS

Uranium	**94%**
Fission products	**5%**
Plutonium	**1%**
Minor actinides	**~ 0.1%**

CONTENT





USED FUEL STOCKPILES:

- ***a concern***:
  - *fissile elements*
  - *radiotoxic*
  - *heat emitter*
- ***an asset***

(1g Pu# 1toe)

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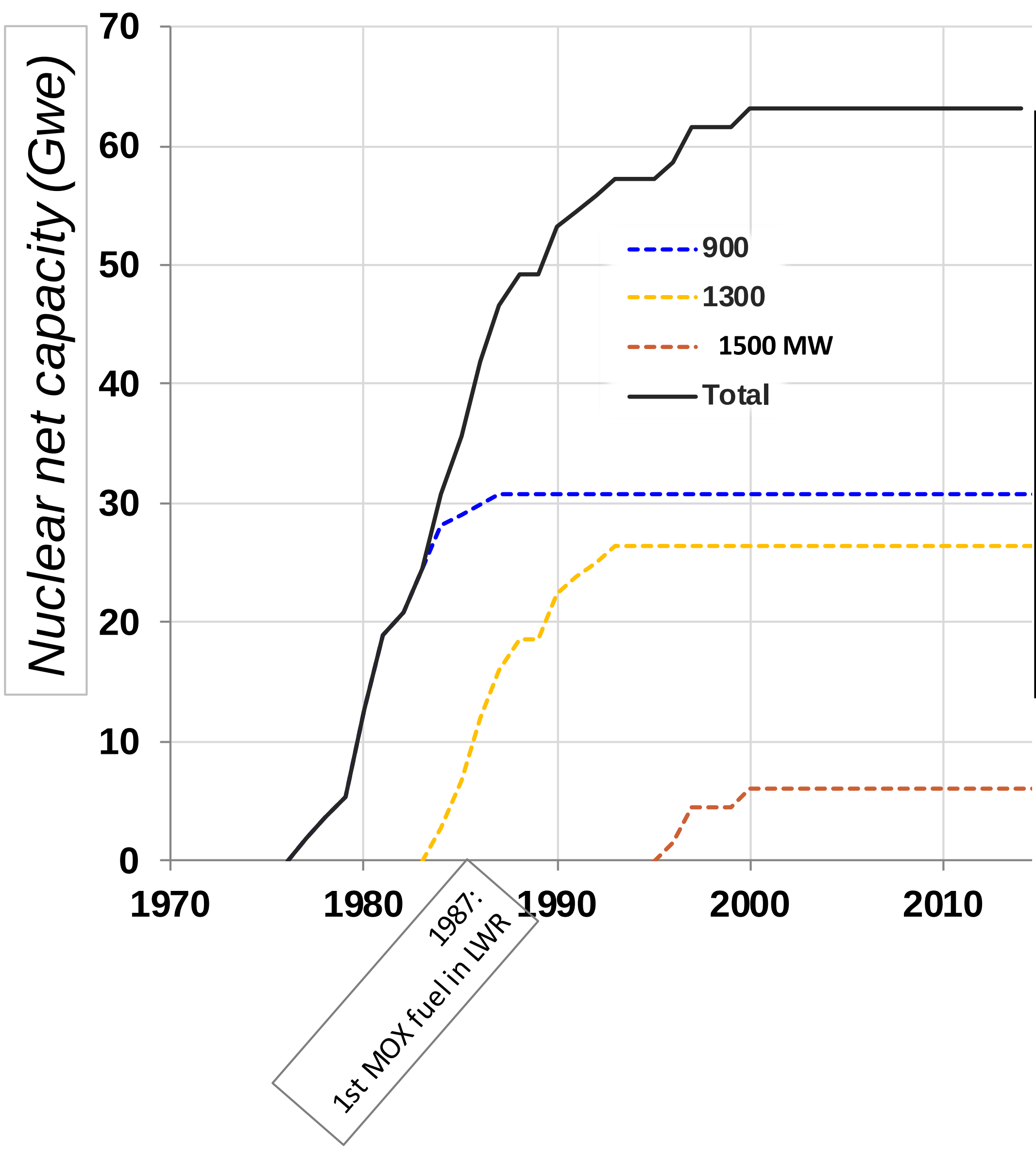
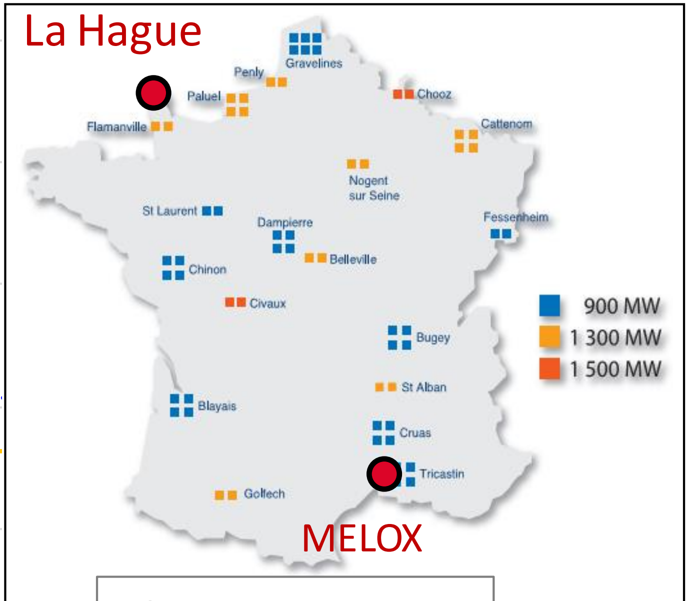
1 – THE CURRENT FRENCH NUCLEAR FUEL CYCLE

THE FRENCH NUCLEAR FLEET

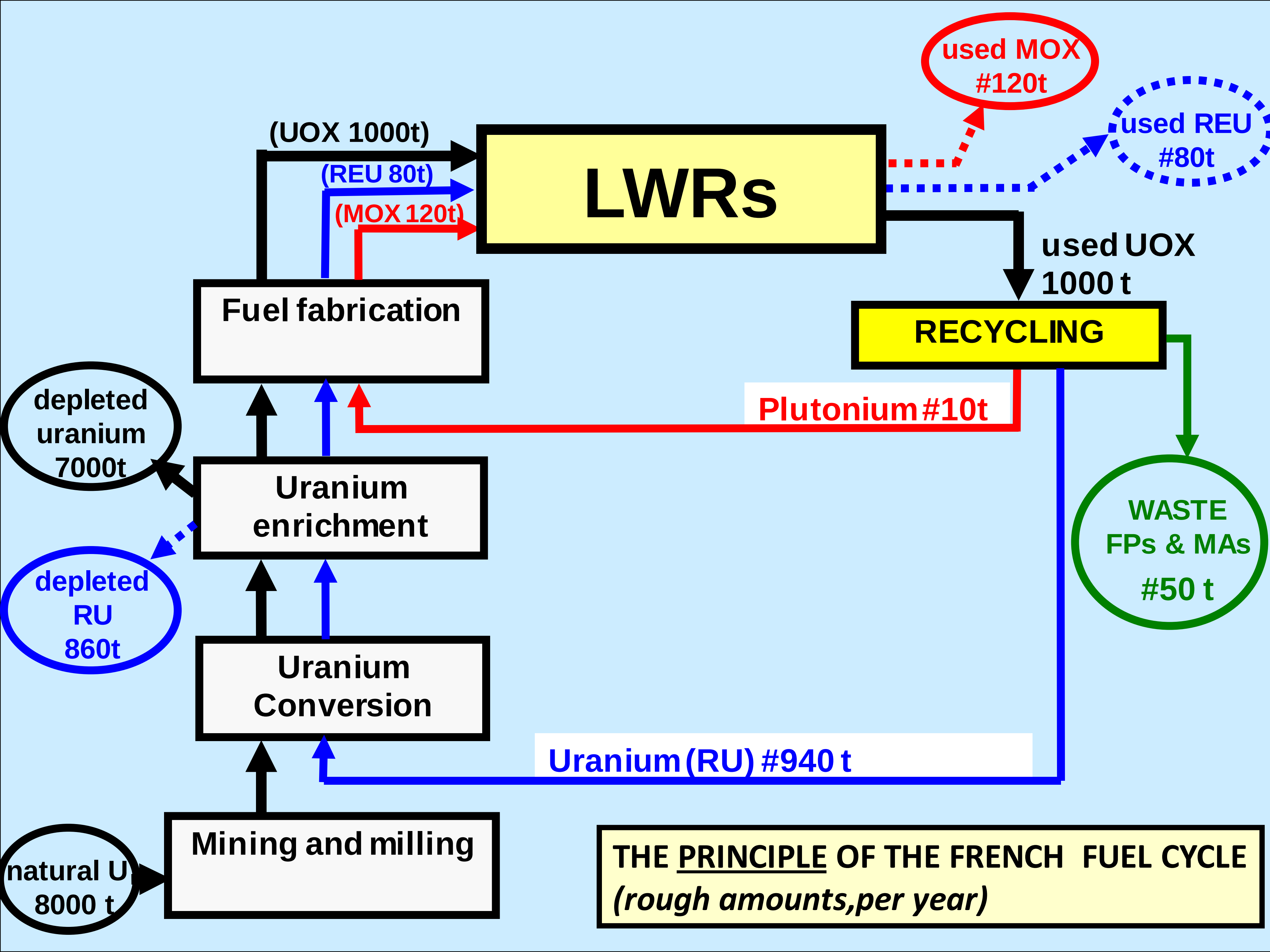




58 LWR

24 licenced for MOX

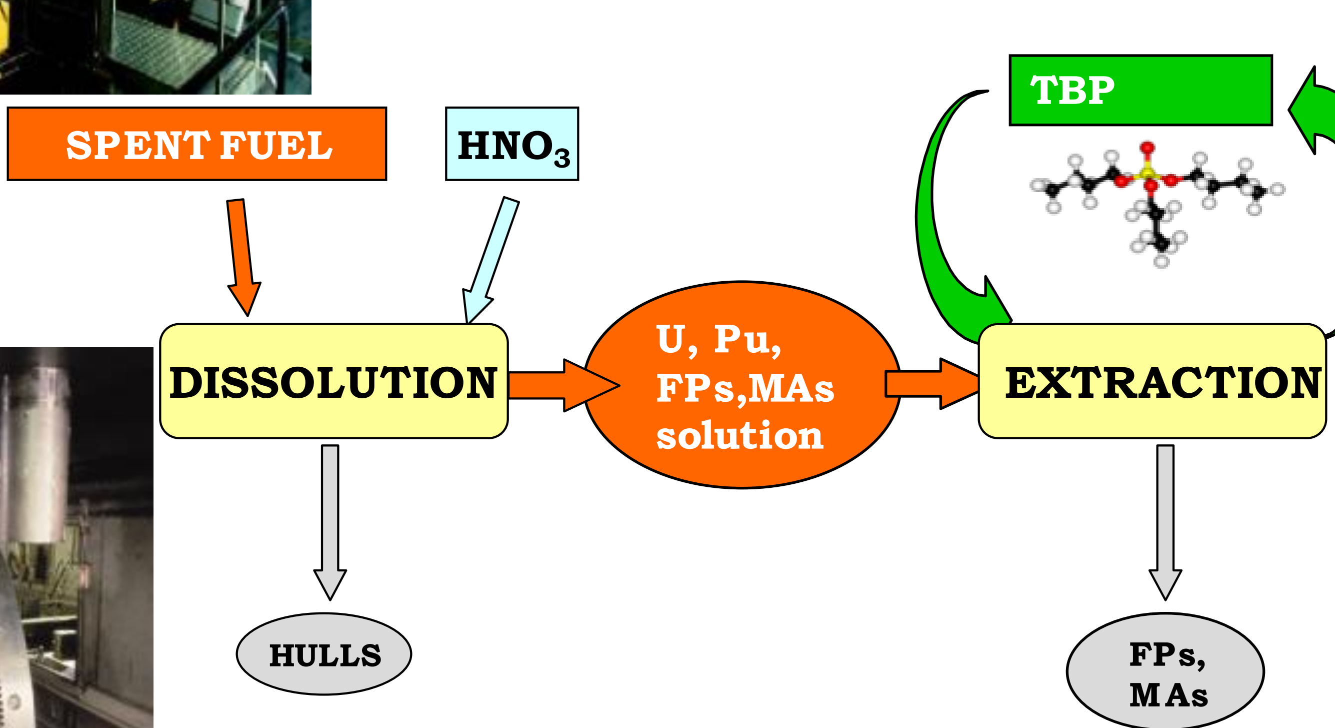
4 licenced for REU



used MOX
#120t
used REU
#80t
(UOX 1000t)
(REU 80t)
(MOX 120t)
LWRs
used UOX
1000 t
RECYCLING
Fuel fabrication
Plutonium #10t
depleted
uranium
7000t
Uranium
enrichment
WASTE
FPs & MAs
#50 t
depleted
RU
860t
Uranium
Conversion
Uranium (RU) #940 t
Mining and milling
natural U
8000 t
THE PRINCIPLE OF THE FRENCH FUEL CYCLE
(rough amounts,per year)

RECYCLING TECHNOLOGIES : DECADES R&D !

high yields…



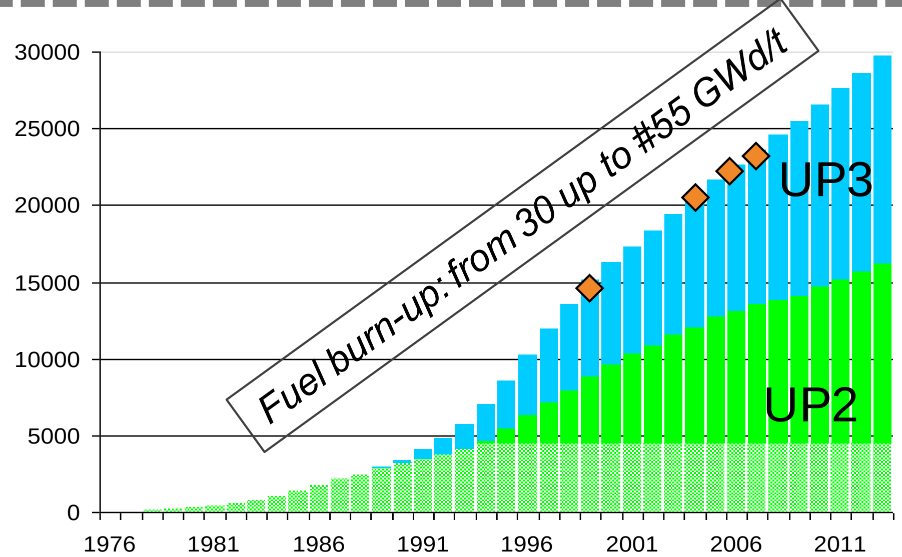
…technological waste
low amount

FINAL WASTE VITRIFICATION

 # <u>17 000 glass canisters</u> produced

 # 10-15 glass canisters /reactor /per year

USED FUEL *RECYCLING* IN FRANCE



La Hague plant

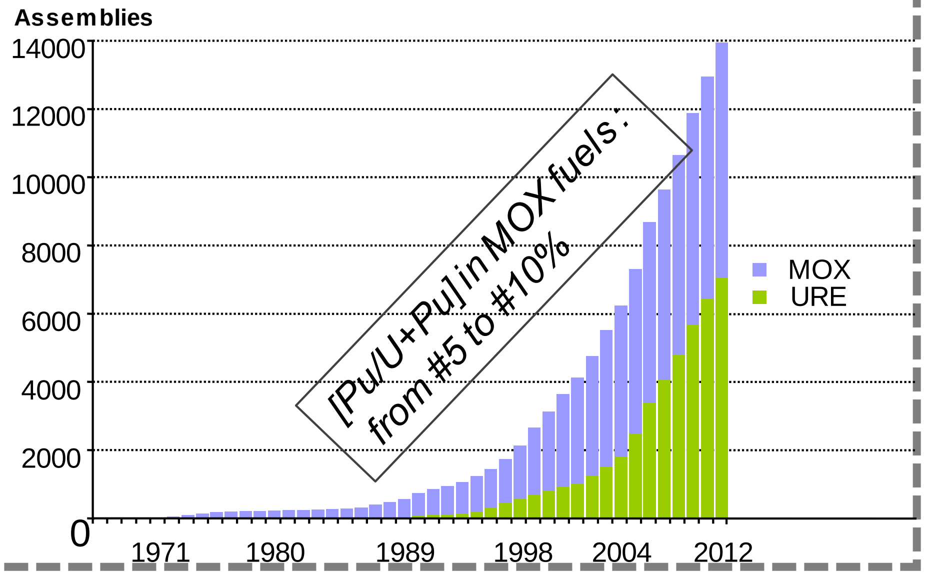
(UNF tons)

> 30 000 tons processed

◆ ***Used MOX fuel (#70 tons processed)***

MOX/REU Fuel re-loading

(sub-assemblies)



 # 2000 tons MOX fuel manufactured

CURRENT RECYCLING STRATEGY : *THE RATIONALE*

- **saving uranium resources**
  (#10% of French nuclear electricity from MOX fuels)

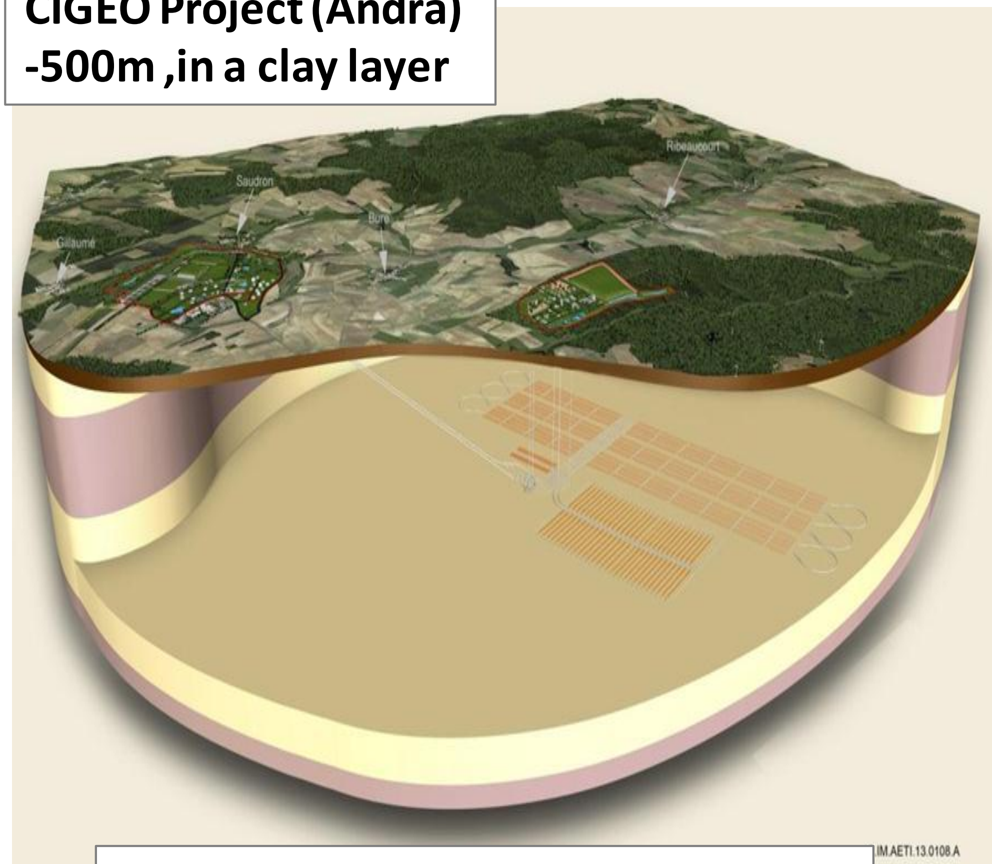
- **safe & secure *ultimate waste without plutonium*;**
  (volume , heat load , radiotoxicity decreased)

- **mastering the growth of plutonium inventory**
  (Pu flux adequacy : Pu from processing= Pu refueled)

- **plutonium safely concentrated in used MOX fuels**
  (available for future use)

FINAL WASTE DISPOSAL

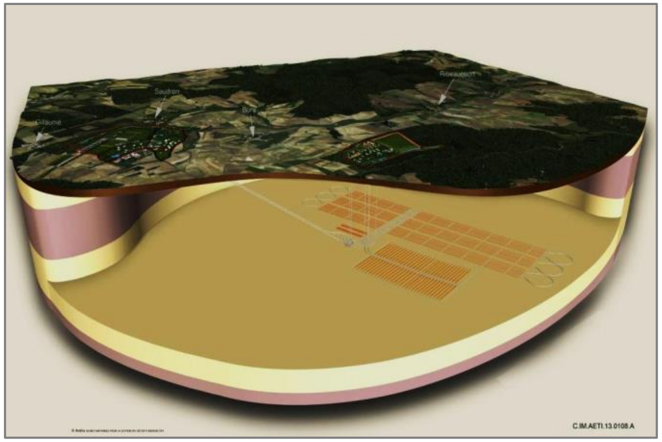
CIGEO Project (Andra)
-500m ,in a clay layer

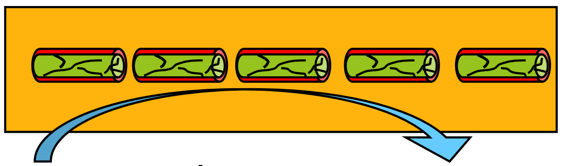


- licence application: # 2017
- active operation : from 2025
  (a preliminary « pilot phase »)

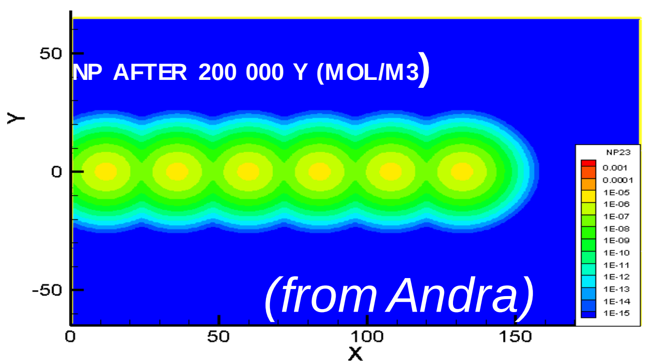
Sockets for glass canisters

GLASS CANISTERS DISPOSAL

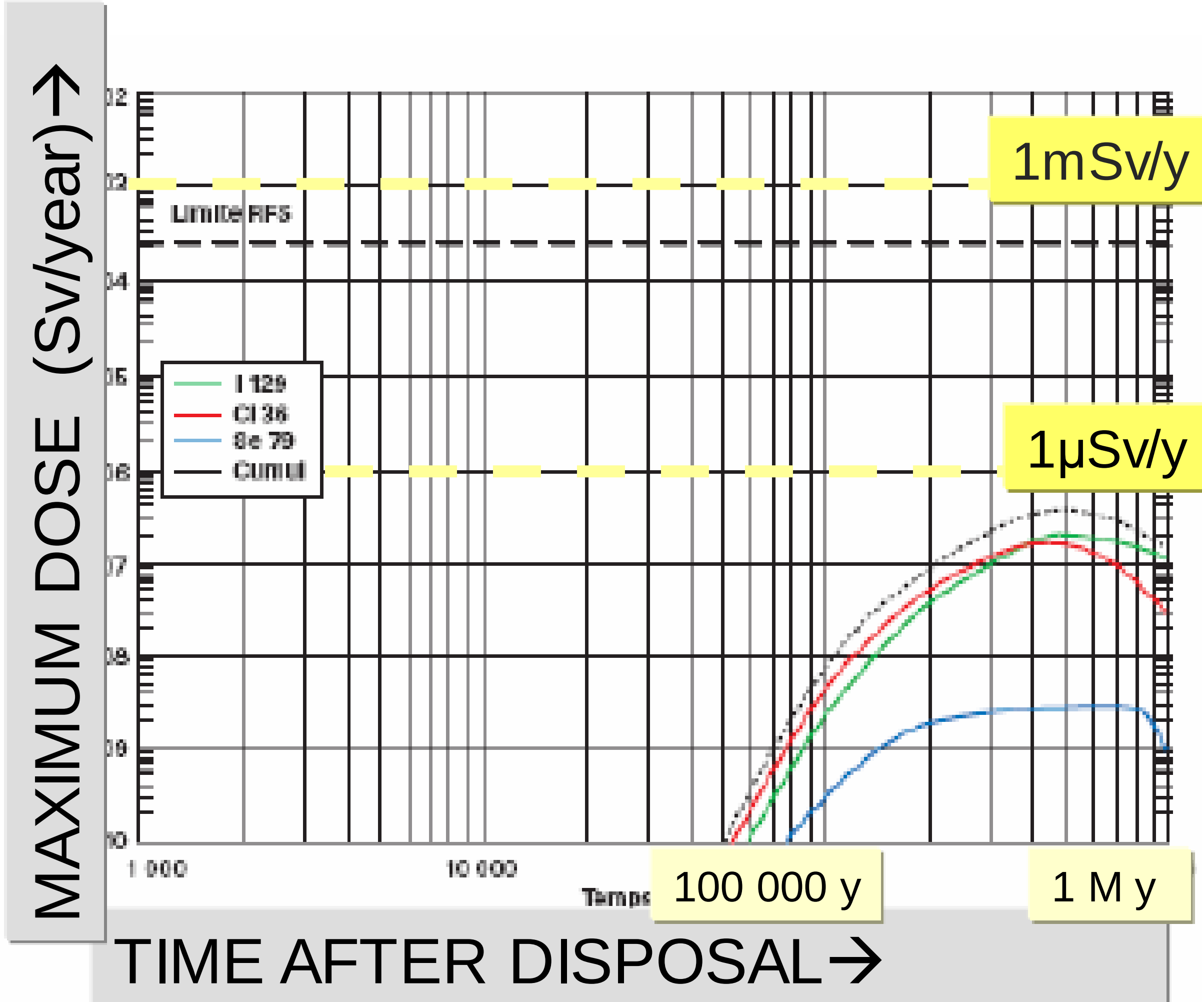




~ 1µm /1000 years
(steady state, 25 °C)



(from Andra)



(ANDRA, « CLAY REPORT », 2005)

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2 - TRENDS & OPTIONS FOR THE FUTURE

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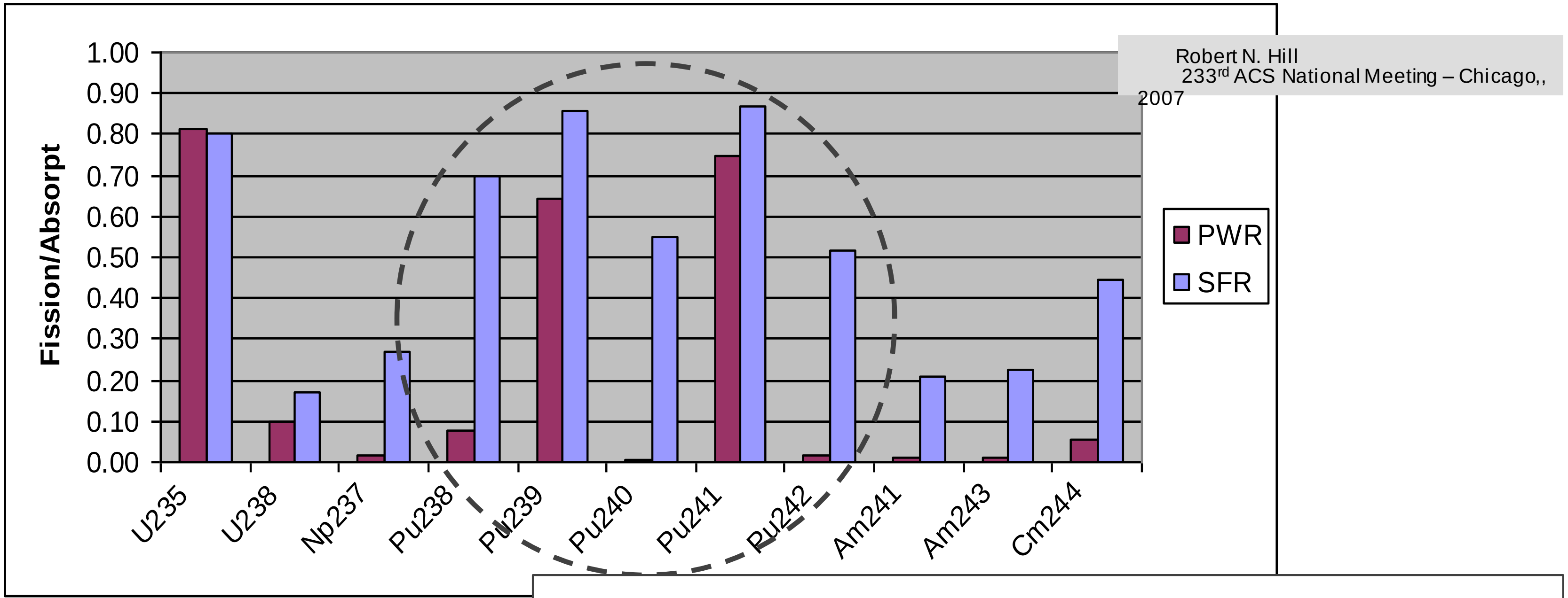
WHY FAST NEUTRON REACTORS ?



Pu burning in FRs favors Pu fission ,
allowing Pu multi-recycle

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(1) **Systematic U & Pu recycle** , (2) in **fast neutron reactors**
- for a sustainable management of nuclear materials & waste,
- avoiding increasing of Pu-bearing stockpiles,
- opening the way to a drastic extension of the use of U resource

CURRENT RECYCLING STRATEGY : *"THE NATIONAL INVENTORY", 2012 (ANDRA)*

- ***used UOX*** **:**

  2010 : 14 000 t (# stabilized)

- ***used MOX*** **:**

  2010: 1300 tons *(increasing 120 tons/year)*

  2035 : 4000t (about # 250t Pu)

- ***depleted U*:**

  2010 : 270 000 t

  2035: 450 000 t

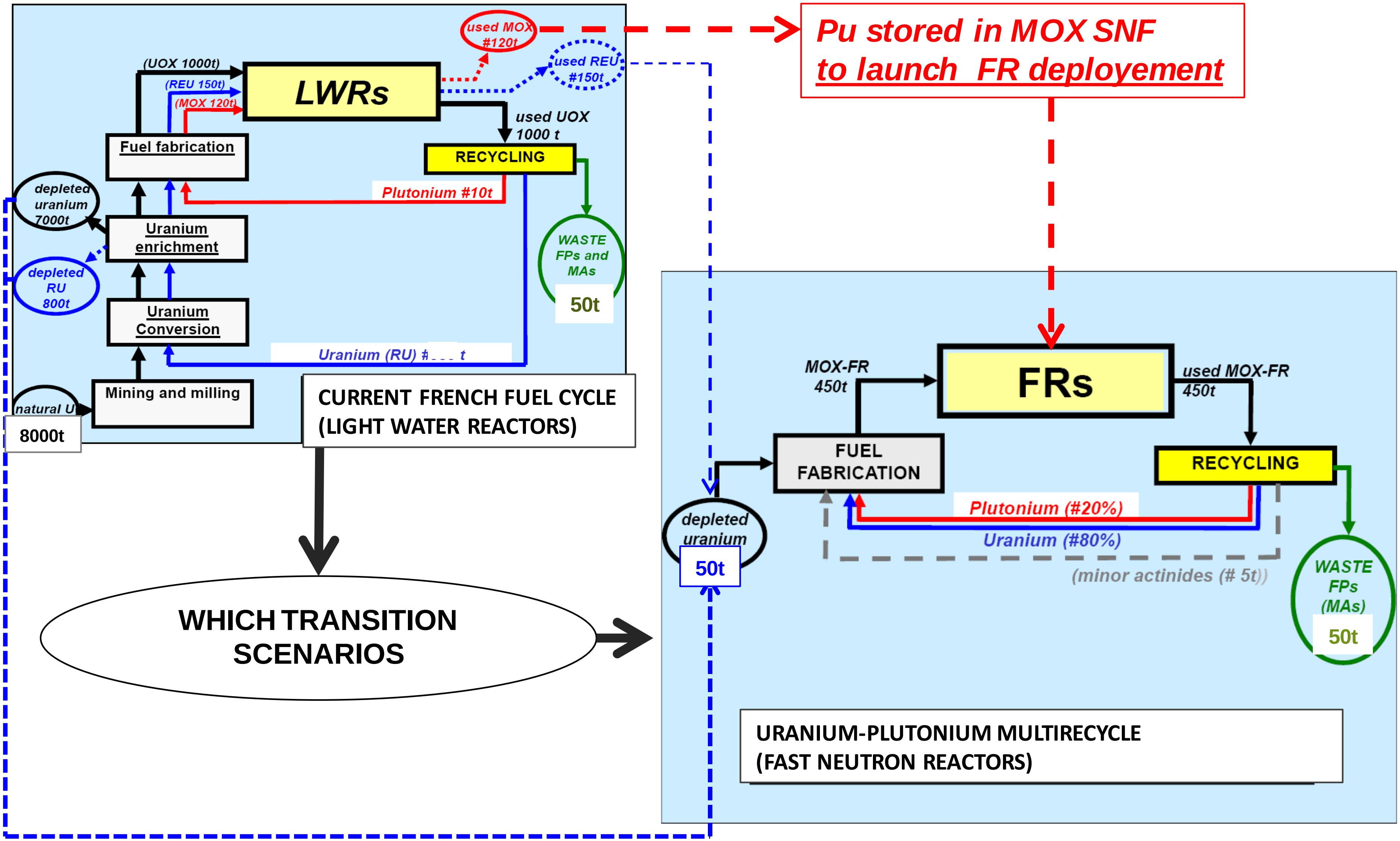
- ***used REU*** **:**

  2010 :320 t

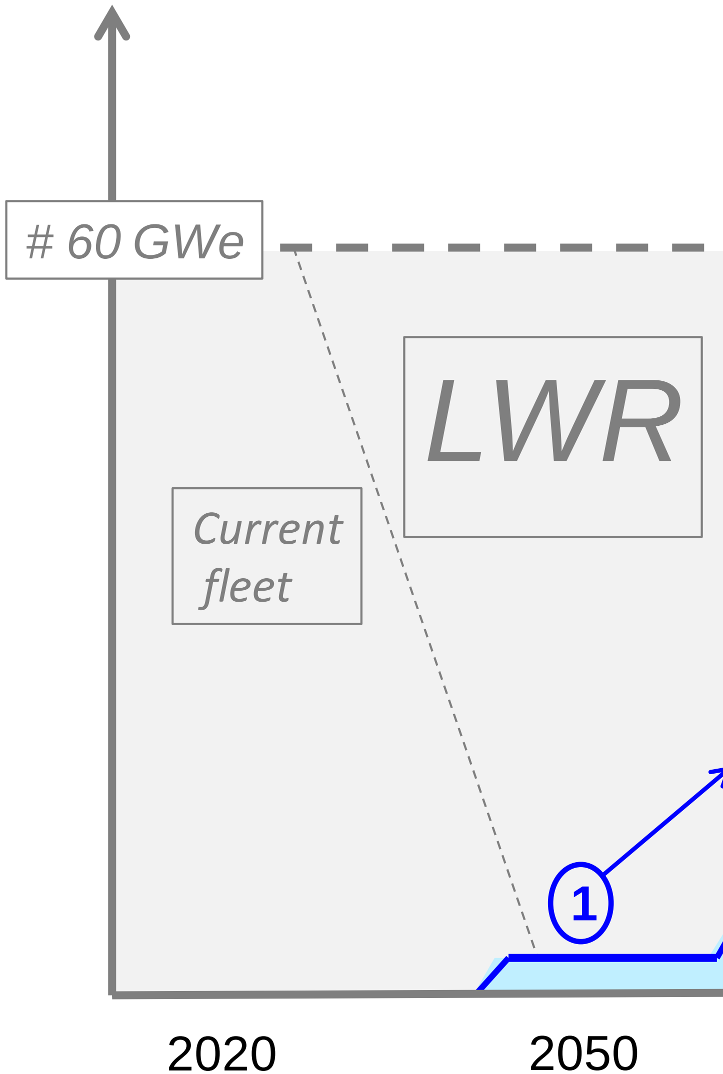
  2035 :1800 t

FROM CURRENT FUEL CYCLE…

TO FAST REACTORS FUEL CYCLES



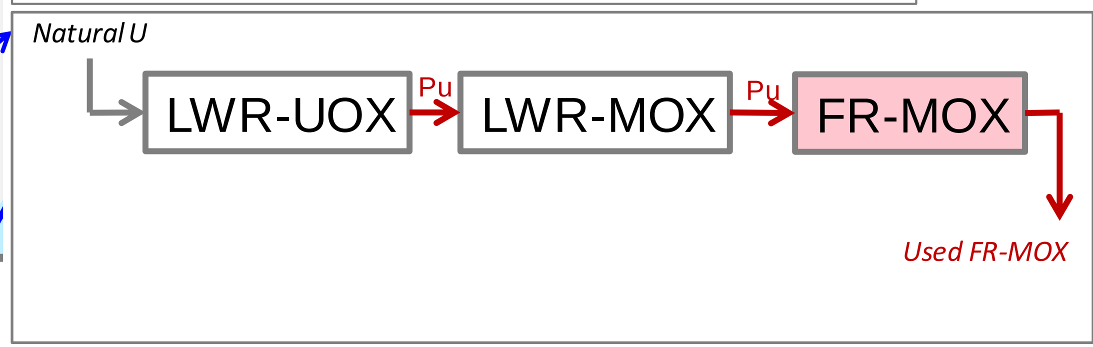
FR REACTORS DEPLOYMENT: *CURRENT SCENARIO STUDIES*



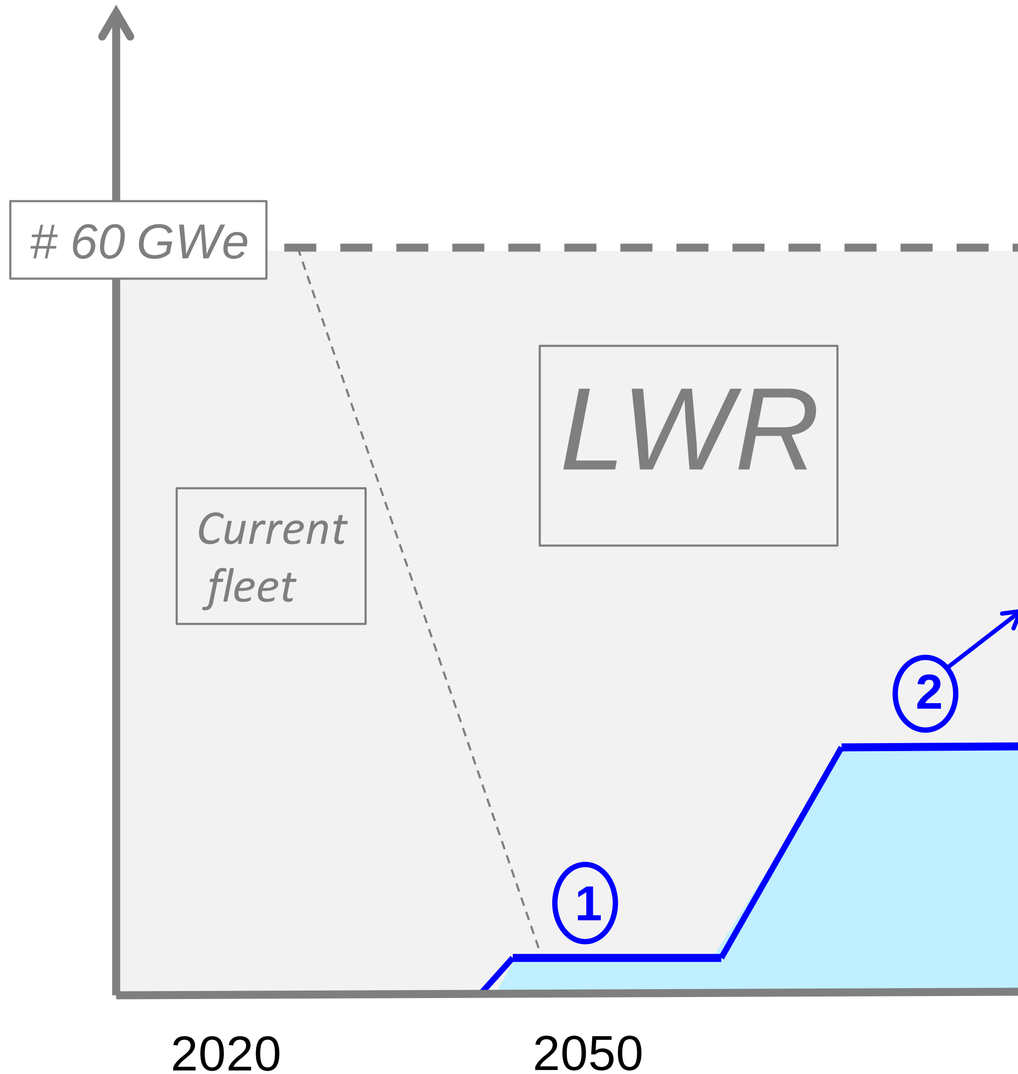
<u>Stage 1</u>: **<u>recycle used LWR-MOX</u>**

a few FR needed (3 – 5 GWe?)

Used MOX-LWR amount stabilized



FR REACTORS DEPLOYMENT:
CURRENT SCENARIO STUDIES

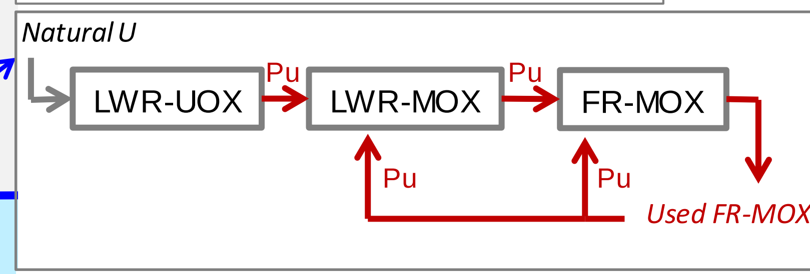


<u>Stage 2</u>: **<u>recycle FR- MOX</u>**

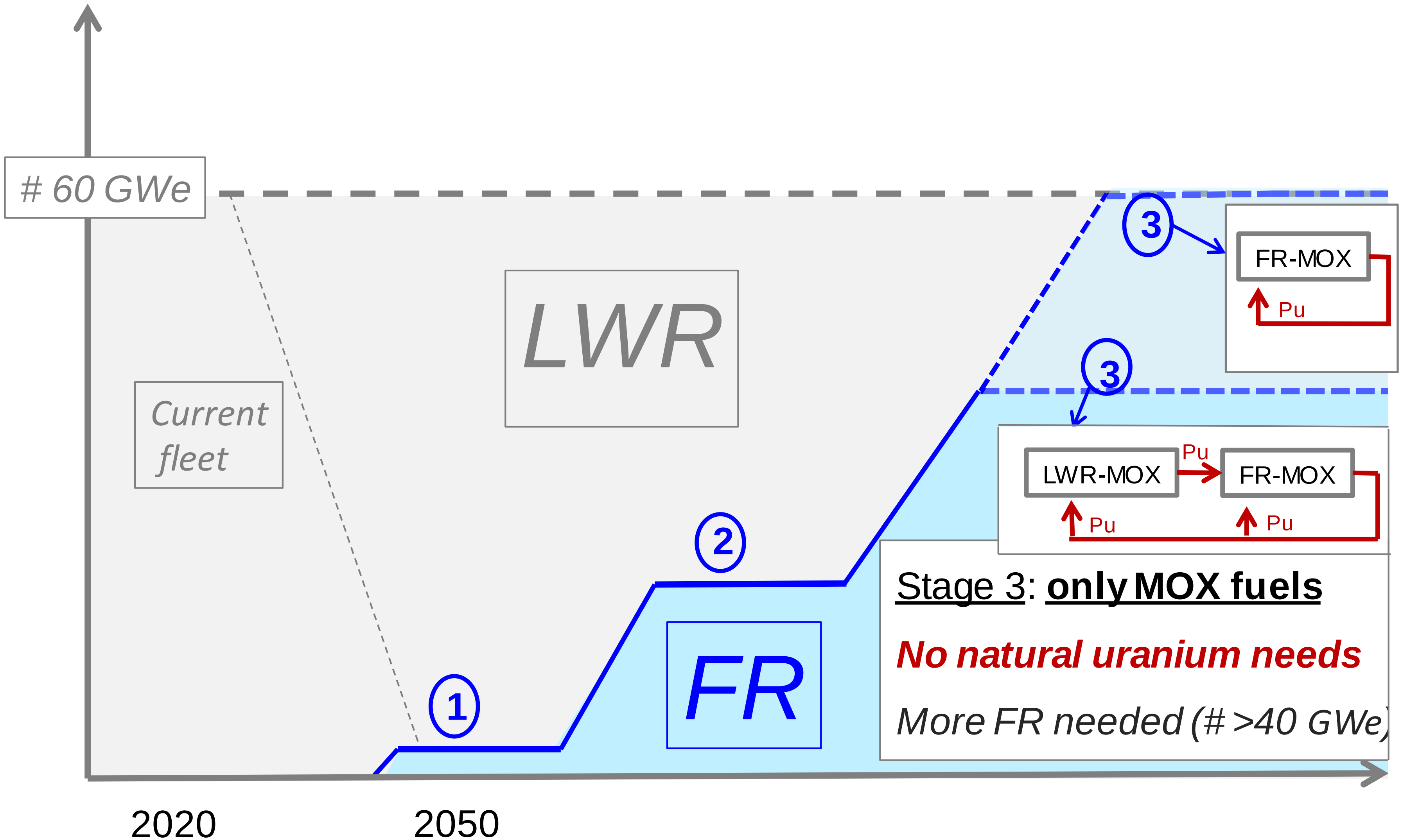
More FR needed (#20 GWe)

Pu multi-recycled

Pu amount stabilized

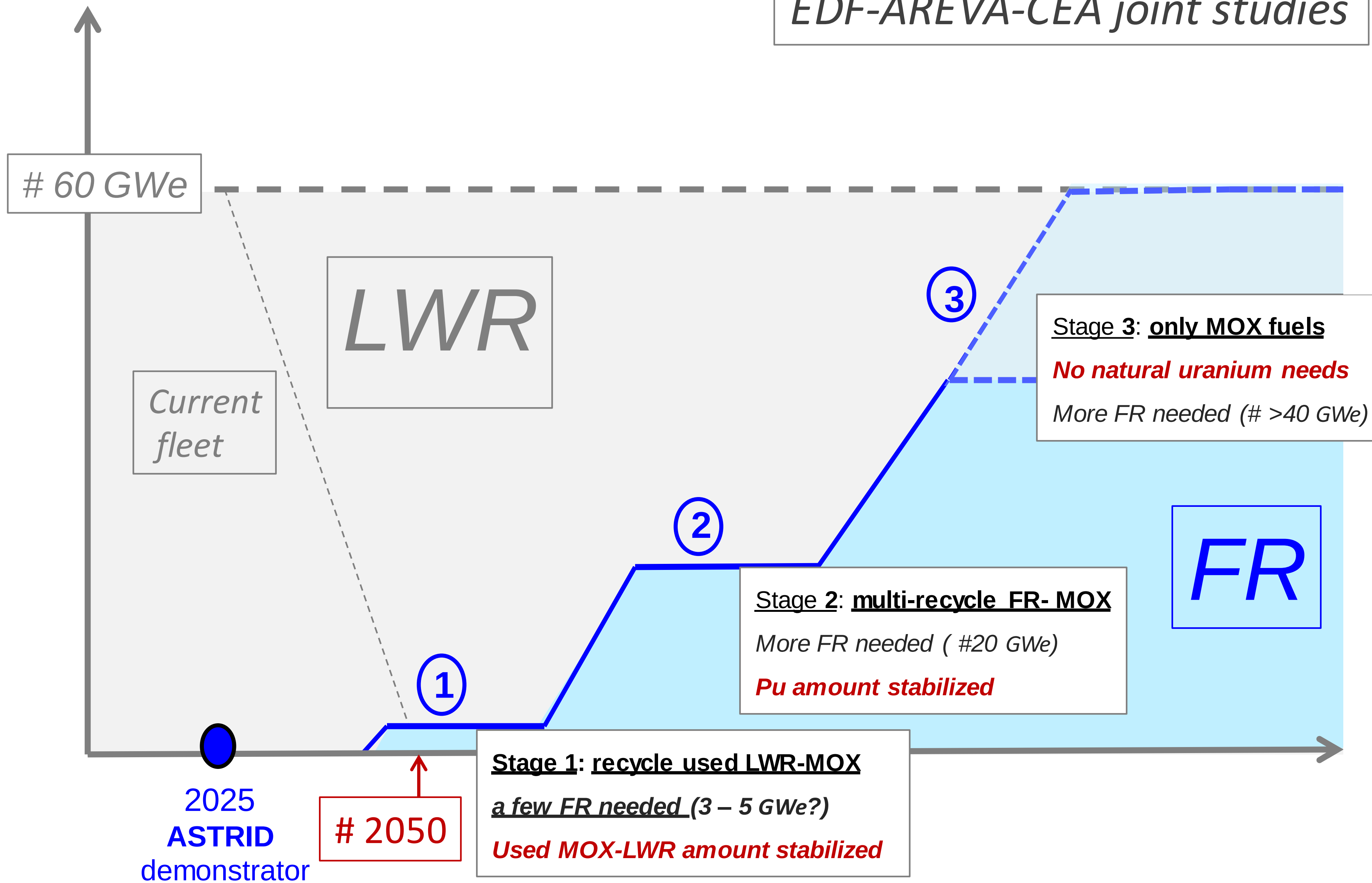


FR REACTORS DEPLOYMENT: *CURRENT SCENARIO STUDIES*



FR REACTORS DEPLOYMENT: *CURRENT SCENARIO STUDIES*

EDF-AREVA-CEA joint studies



FUEL CYCLE OPTIONS PERFORMANCE ASSESSMENT (1) NUCLEAR MATERIALS

PRELIMINARY RESULTS

	OPEN CYCLE	**MONO-RECYCLE *LWR***	**BI-RECYCLE LWR – (FR)**	**MULTI-RECYCLE LWR - FR**	**MULTI-RECYCLE no U needs FR**
RNR share (GWe %)	*0*	***0 %***	**5%**	*40%*	***100%***
Natural U consumption *(t/y)*	*8000*	**6500**	**6000**	**2500**	**0**
Pu net Production *(t/y)*	+ *10,5*	**+ 7,5**	**+ 7**	**0**	**0**
Used fuels amount *(t/y)*	+ *1000* *UOX*	**+ 160** *MOX+REU*	**+ 100** *RNR+REU*	**stabilized**	**stabilized**

(tons / year)

CEA , report to be issued, July 2015
(scenario studies,AREVA-EDF-CEA, 420 TWh/year)
(HAVL footprint estimates from ANDRA-CEA studies)

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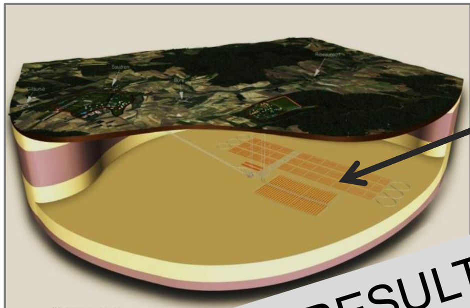
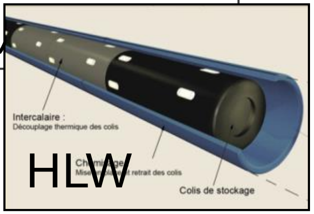
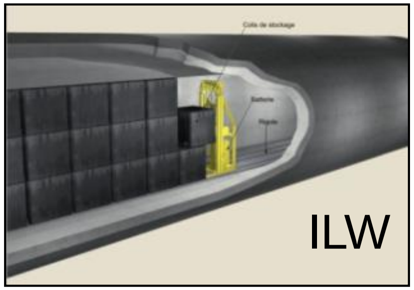
FUEL CYCLE OPTIONS PERFORMANCE ASSESSMENT (3) REPOSITORY FOOTPRINT



REPOSITORY FOOTPRINT
(HLW sockets)



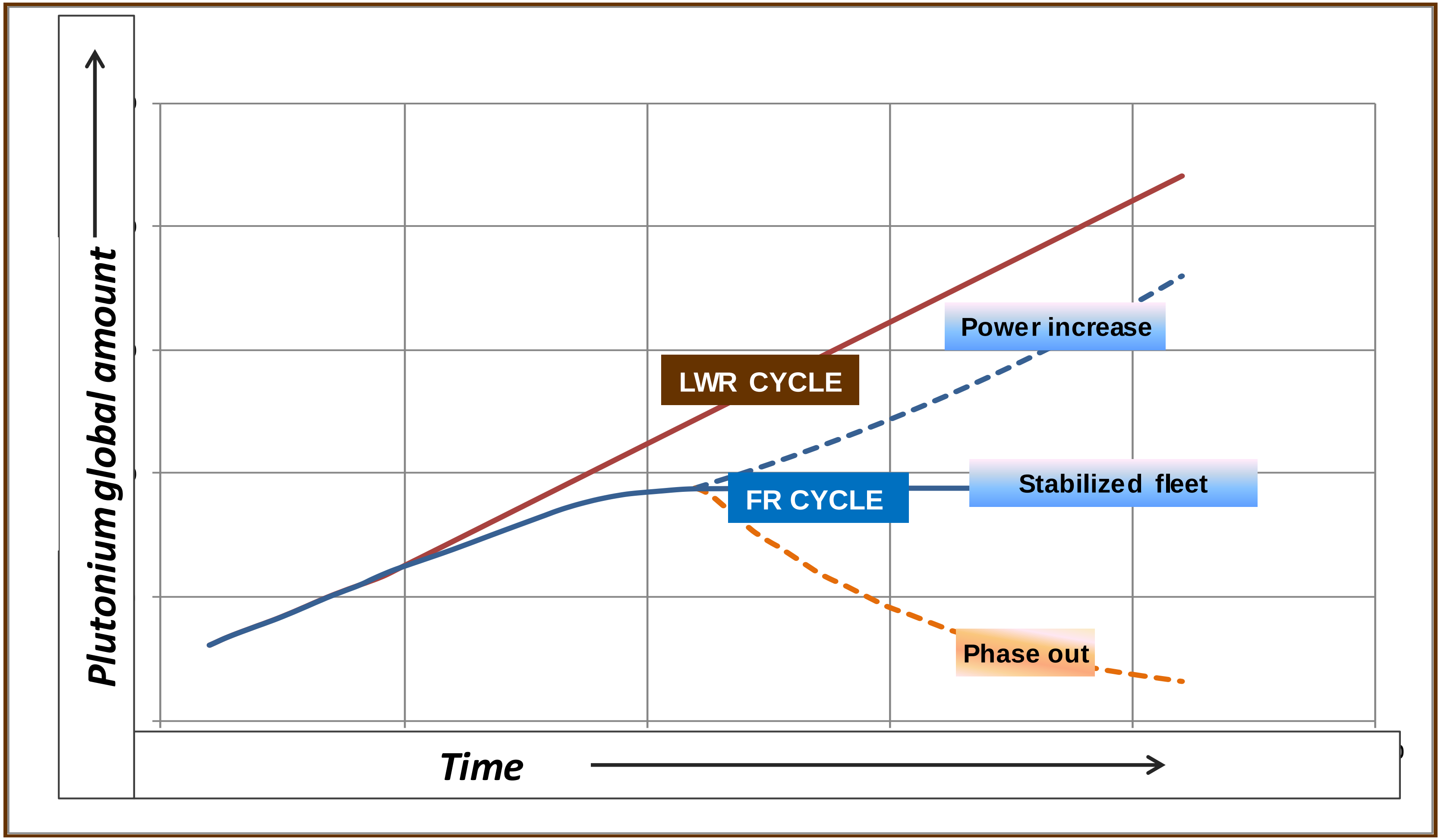


PRELIMINARY RESULTS

	OPEN CYCLE LWR	**MONORECYCLE LWR**	**BI-RECYCLE LWR-FR**	**MULTIRECYCLE FR**	**MULTIRECYCLE All TRU- FR**
HLW WASTE FOOTPRINT (m^2/TWh)	490	**150**	**170**	**170**	**20**
USED FUELS POTENTIAL ADDITIONAL FOOTPRINT(m^2/TWh)	*0*	*180*	*120*	*0*	*0*
GLOBAL *POTENTIAL* FOOTPRINT (m^2/TWh)	490	**330**	**290**	**170**	**20**

CEA , report to be issued, July 2015
(scenario studies,AREVA-EDF-CEA, 420 TWh/year)
(HAVL footprint estimates from ANDRA-CEA former studies)

FAST NEUTRON REACTORS *FLEXIBILITY*



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3 – R&D CHALLENGES

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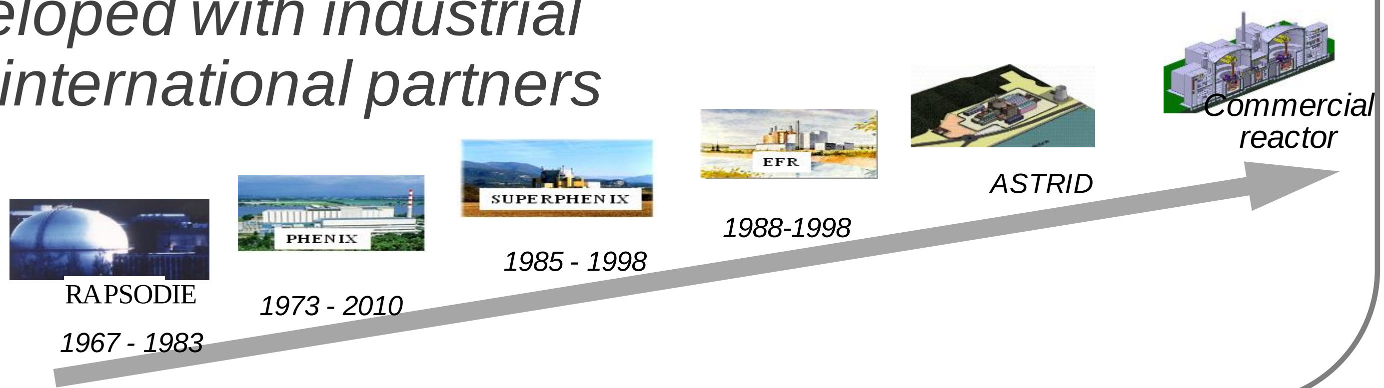
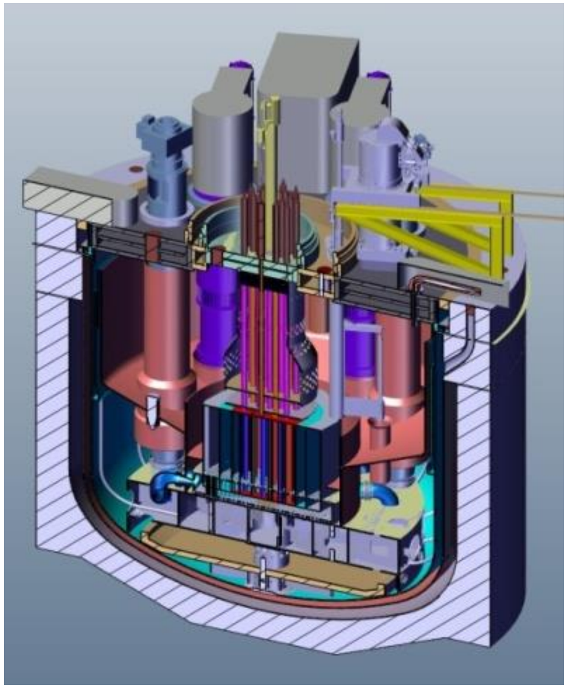
FAST NEUTRON REACTORS

- Sodium Fast Reactor, the reference option :
  [ASTRID, the technology demonstrator]
  - *maturity, possible further improvements (safety, operability, economics)*
  - *developed with industrial and international partners*

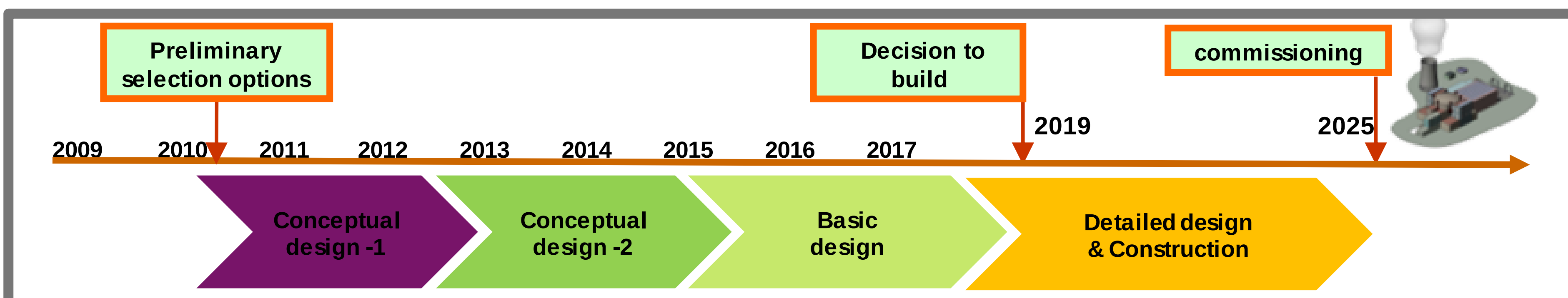


- *Gas-cooled Fast Reactor, a long-term option:*
  - *attractive potentialities but heavy challenges…*

THE ASTRID PROGRAM



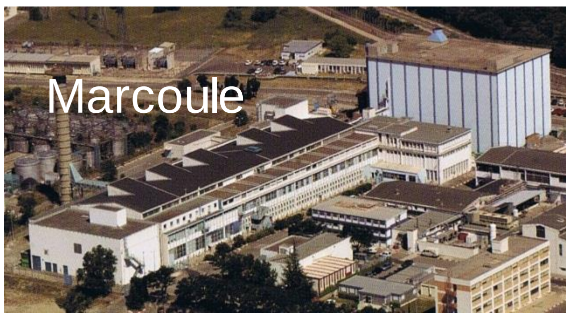
- *600 Mwe* , ***«*** pool » type
- ***<u>oxide fuel</u>****, transmutation capabilities*
- *<u>Innovative design</u>:*
    - self-sustainable **safer** core
    - *core catcher, residual heat removal*
    - *power conversion system*



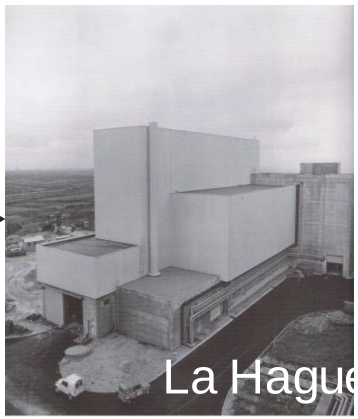
PROCESSING USED FUELS

- CURRENT RECYCLING TECHNOLOGIES:
a robust basis for oxide fuels recycle!

- **ADAPTATION** ***to fast neutron reactor fuels (higher Pu content)***

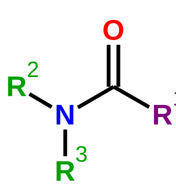


25 tons FR-MOX already recycled



- **IMPROVEMENT** ***of the technologies***

Recently : *UPu co-management*
cold crucible melter vitrification



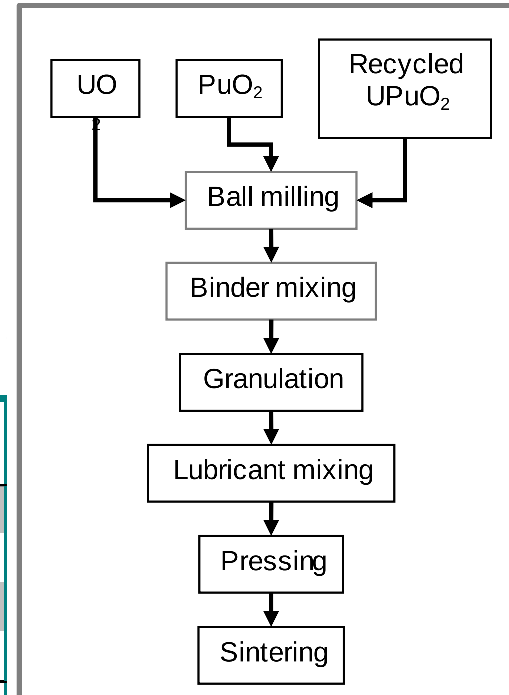
Tomorrow : *single-cycle, redox-free process?* ***(to simplify!)***

FUEL FABRICATION TECHNOLOGIES

***POWDER METALLURGY**, the reference option for FR-MOX fuels*

- A SIGNIFICANT EXPERIENCE

(CFCA , Cadarache)



Oxyde SFR fuels fabrications in ATPu between 1963 and 1999

Réactors	***Nb of pins***	***Nb of pellets (millions)***	***Pellets (t_{HM})***	***Pu (t_{HM})***
Rapsodie	28 536	1	1,2	0,35
Phénix	180 941	12,6	32,4	8,2
Super-Phénix	208 396	16,9	71,2	12,7
PFR (GB)	9 555	0,7	1,6	0,54
Total	**427 428**	**31,2**	**106,4**	**21,8**

- TO BE ADAPTED *(Pu from LWR-MOX, increased BU)*

- TO BE IMPROVED *(new precursors)*

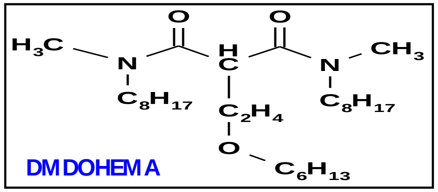
[ASTRID FUEL FABRICATION FACILITY UNDER DESIGN]

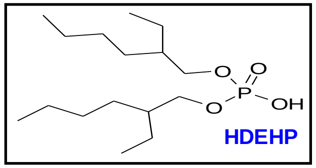
MINOR ACTINIDE P&T

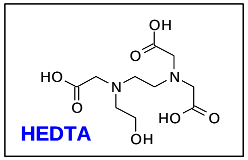
SNF → PUREX /COEX → DIAMEX /SANEX → FPs.

PUREX /COEX → U, UPu

DIAMEX /SANEX → Am (and Cm)







MA recovery innovative processes have been successfully experimented,*<u>at lab-scale</u>*

[SANEX 2005, GANEX 2008, EXAm 2010] (kgs, genuine SNF)

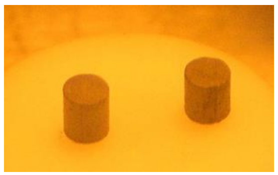
<u>R&D goals</u>: optimize and pilot-scale approach

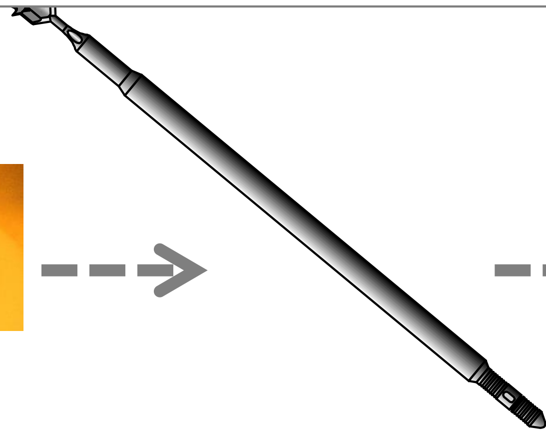
separation, MA-bearing fuels fabrication, transmutation:

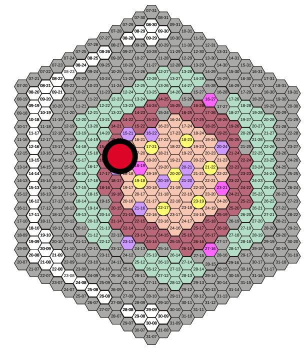
<u>a long way to reach industrial feasability</u>

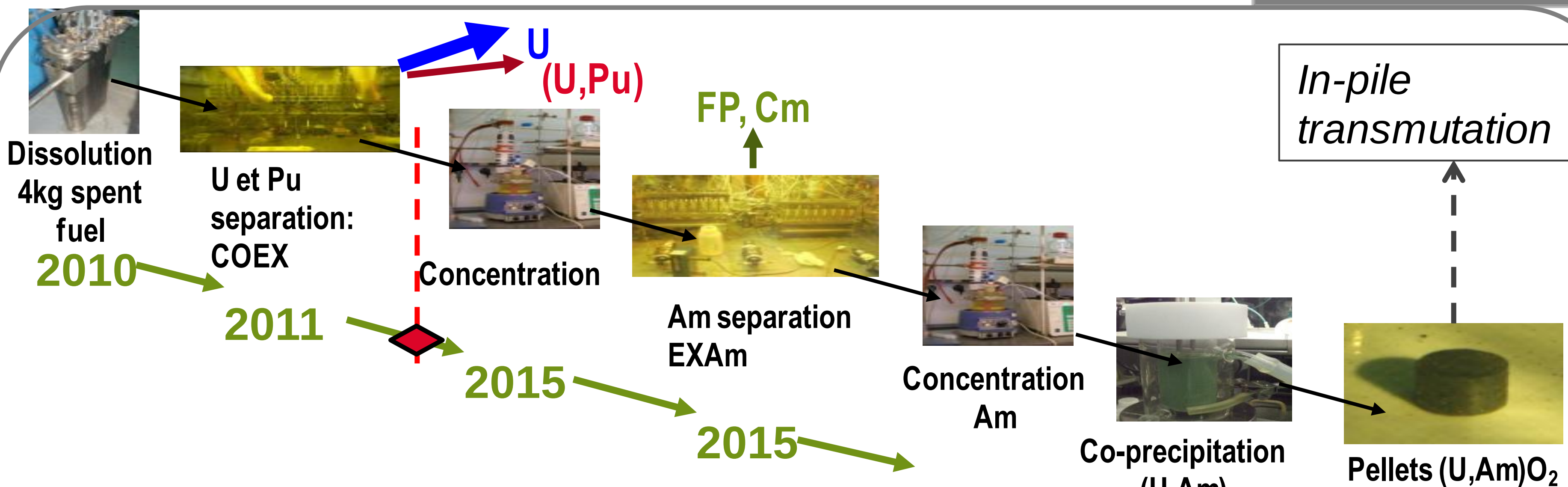
AMERICIUM TRANSMUTATION

Pin-scale transmutation experiments









The « integral experiment » for Am P&T

« en résumé… »

> Reprocessing and recycling today:

- **well-proven technologies, at commercial scale**
- **thanks to important R&D (research & industrial bodies)**
- **provides significant benefits:**
  - *natural resource savings*
  - *optimization of final waste management*
  - *mastering plutonium inventory*

> A first step towards more and more sustainable systems

- **a "step by step approach,**
- **with the progressive deployment of generation IV reactors**
  (for Pu full burning, natural uranium utilization drastic increase, long-lived elements transmutation…)

> The ASTRID program, an opportunity for technical demonstration and *for international cooperation*

INCREASING SUSTAINABILITY BY RECYCLING …

no recycle (« once through »)

U Pu recycling in LWRs

U Pu multi-recycling in FRs

All TRU recycling…

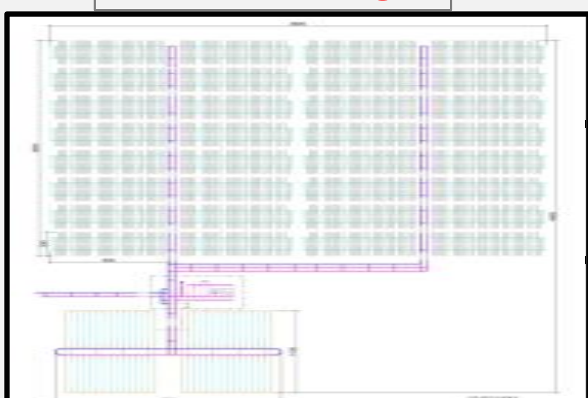
HLW VOLUME

150000 m^3

Once through	Pu recycle	all-TRU recycle
100	10	10

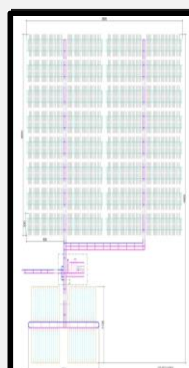
HLW « FOOTPRINT »

Once through



100

Pu recycle



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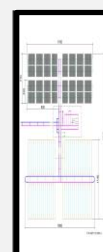
all-TRU recycle



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THANK YOU

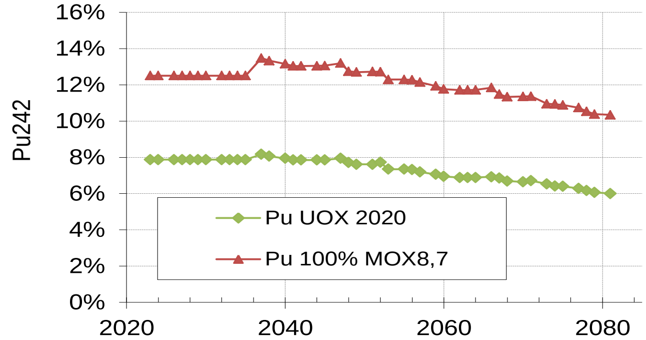
FOR YOUR ATTENTION !

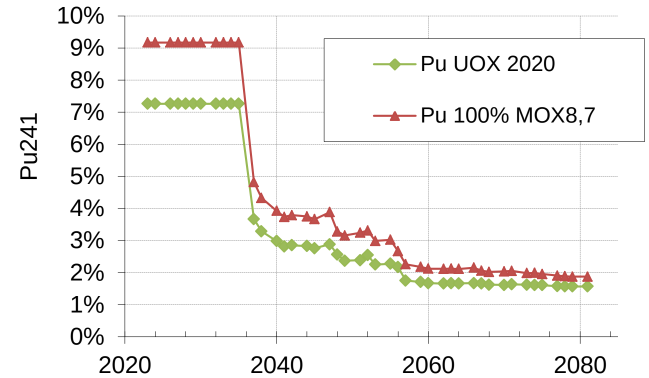
PLUTONIUM *MULTI*-RECYCLE

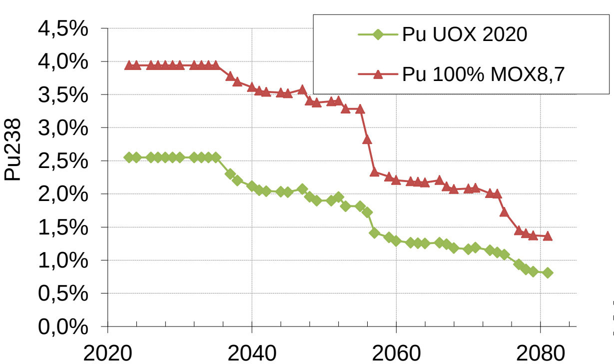
isotop	Pu from UOX	Pu from MOX
238	2.48	3.8
239	53.3	39.9
240	24.8	31.1
241	12.1	13.4
242	7.3	11.8

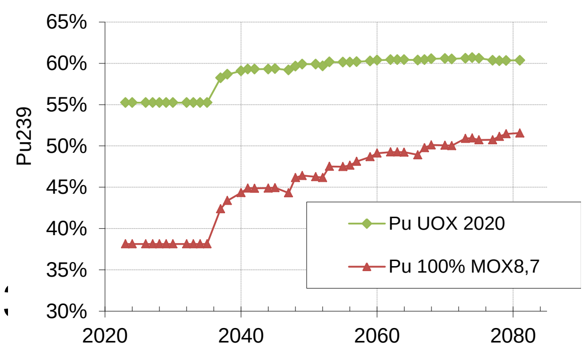
Pu recycle in LWRs

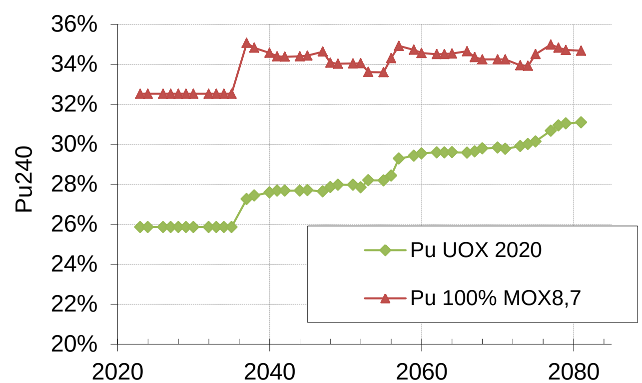
Pu recycle in FRs







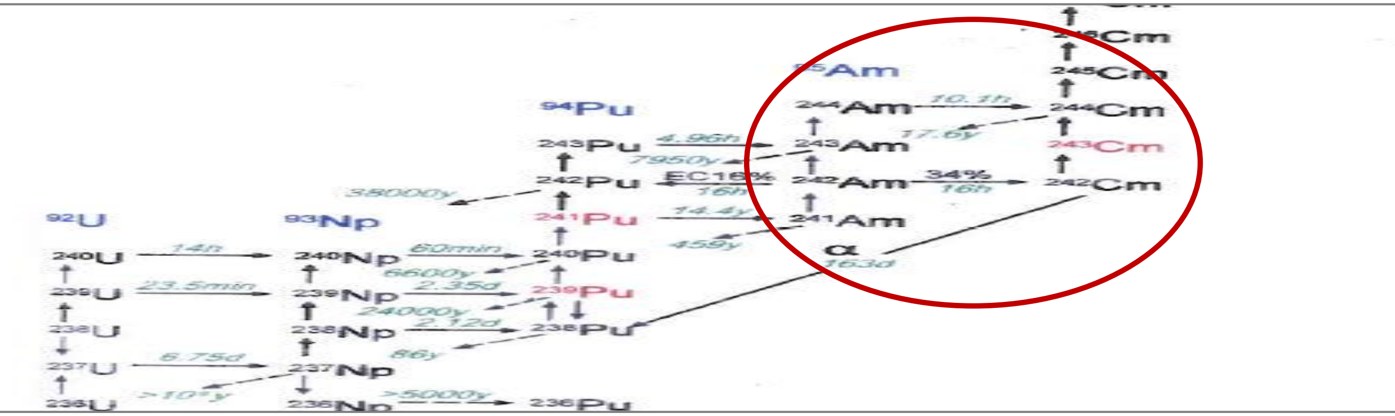




MINOR ACTINIDES TRANSMUTATION: *DRIVERS...*

<u>Minor actinide</u> removal could provide an optimization of final waste management:

- *by decreasing <u>waste long-term radiotoxicity</u>*
- *by decreasing the <u>repository footprint</u> (Am recycle mainly)*



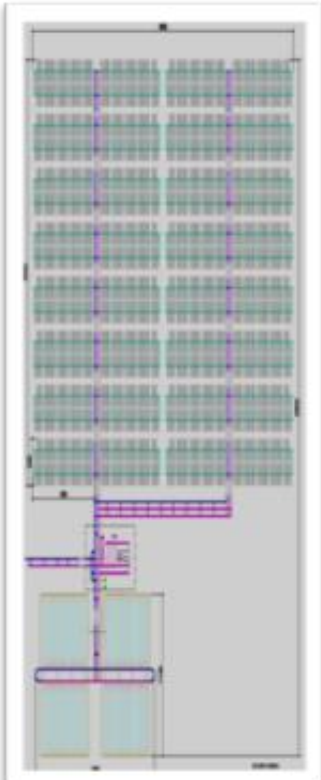
Fast neutron reactors incentives:

- **MA production : *3 -5 times lower in FR (vs. LWR)***
- **MA transmutation : possibly quantitative in FR**

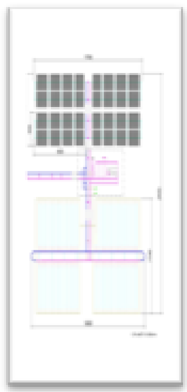
(MA multi-recycle)

MINOR ACTINIDES TRANSMUTATION: *DRIVERS…*

1500 ha total, among which **1175 ha HLW**,
7 Mm3 excavated



no transmutation



MA transmutation

430 ha total, among which **120 ha HLW**,
3 Mm3 excavated

[Andra-CEA 2012, cooling phase 120 years]

REPOSITORY FOOTPRINT